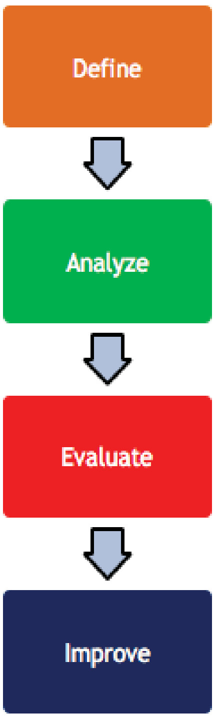
Appendix A: A Short VMEA Reference Guide

Here a short reference guide is presented for the evaluation of a probabilistic (or enhanced) VMEA. The guide follows the following steps:



1. **Target Function Definition.**
   For example, life of a component, maximum stress or largest defect.
2. **Uncertainty Sources Identification.**
   Identify all sources of uncertainty (scatter, statistical, model).
3. **Sensitivity Assessment.**
   Evaluate the sensitivity coefficients of the sources of uncertainty.
4. **Uncertainty Size Assessment.**
   Quantify the size of the different sources of uncertainty.
5. **Total Uncertainty Calculation.**
   Combine the contributions from all uncertainty sources.
6. **Reliability and Robustness Evaluation.**
   Find the dominating uncertainties or derive safety factors.
7. **Improvement Actions.**
   Identify uncertainties that are candidates for improvement actions.

1. Target Function Definition

The reliability target may be a specified life or the load/strength ratio.

In the life case the target function is defined as the difference between the logarithm of the calculated nominal life and the logarithm of the target life,

$$\ln(N) - \ln(N_{target}).$$

In the load/strength ratio case the target function is defined as the logarithmic difference between the estimated load and the estimated strength,

$$\ln(S) - \ln(L).$$

2. Uncertainty Sources Identification

The schematic description of the life assessment for a MEC is seen in the figure below, where the red and brown error bars represent *possible model errors (uncertainty)* and *variation (scatter),* respectively.

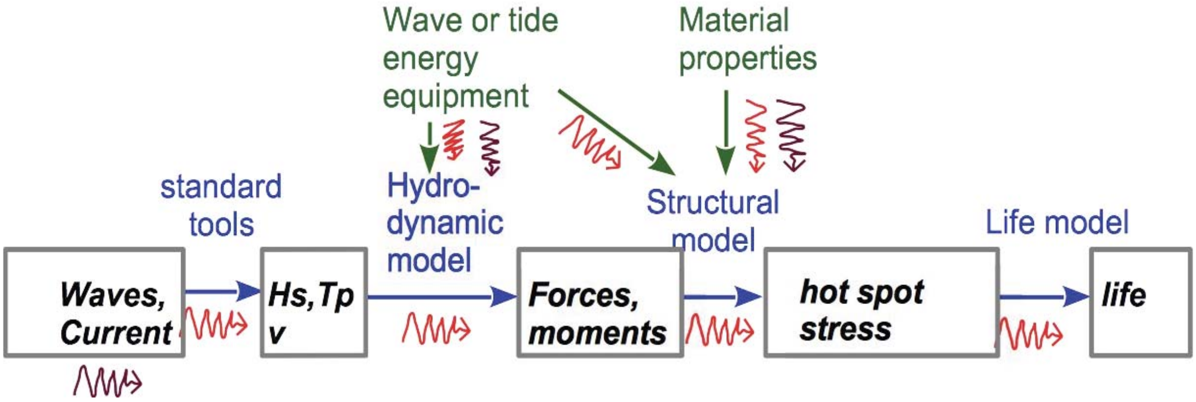


Figure: Schematic description of the life assessment for a MEC.

From this scheme one can list a number of typical uncertainty sources that usually need to be considered in the VMEA analysis:

- Marine Loads:
  - Between and within site variation (scatter)
  - Load estimation uncertainty (uncertainty)
- Hydrodynamic model:
  - Hydrodynamic model errors (uncertainty)
  - Hydrodynamic model parameter uncertainties (uncertainty)
  - Marine growth (uncertainty)
- Structural model:
  - Structural model errors (uncertainty)
  - Structural model parameter uncertainties (uncertainty)
  - Geometric tolerances (scatter)
- Strength/life:
  - Strength/life scatter (scatter)
  - Life model error (uncertainty)
  - Life model estimation uncertainty (uncertainty)
  - Damage accumulation model error (uncertainty)
  - Multi-axial effects (uncertainty)
  - Corrosion effects (uncertainty)

Of course, for each specific case there may be other sources that need to be considered.

3. Sensitivity Assessment

In case the uncertainty size is judged by means of variation in the target function, then the sensitivity coefficient is unity. This is also the case if the judgement is given in percentage variation of the anti-log of the target function.

If the target function is the difference between log strength and log load, then percentage variation by means of load or strength results in the sensitivity equal to unity.

In case the uncertainty size is measured in any other unit than the output of the target function, then the sensitivity is the partial derivative of the target function with respect to the uncertainty source in question.

This sensitivity can in most cases easily found by making two calculations of the target function. The factor of interest is varied while the others are kept fixed. It is recommended to choose the step in in the order of one or two standard deviations of the uncertainty source in question, then the two calculations can be:

1. one with nominal inputs, and
2. one where the uncertainty source in question is changed to a value two standard deviations closer to the more severe case.

The difference between the two calculated target functions is then divided by two standard deviations to get the actual sensitivity coefficient.

$$c_i = \frac{f(X_{i,nom}) - f(X_{i,nom} \pm 2 \cdot s_i)}{2 \cdot s_i}.$$

4. Uncertainty Size Assessment

Each source of uncertainty is given a measure of its size by means of a standard deviation. There are different ways to assess the uncertainty size:

1. If a set of observations of the variable of interest is available, the standard deviation is simply calculated by standard statistical tools. If the number of observations is less than 30, then the the calculated number is adjusted by a *t*-correction according to the table below.

$$s_1 = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2}, \qquad \bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i.$$

2. In case the mean value of a set of observations is used to calculate the nominal strength or load, then its uncertainty is the standard deviation of the observations divided by the square root of the number of observations. The *t*-correction is chosen according to the table below.

$$s_2 = \frac{s_1}{\sqrt{n}} = \sqrt{\frac{1}{n(n-1)} \sum_{i=1}^{n} (x_i - \bar{x})^2}.$$

3. If only the minimum and maximum values are available, then the standard deviation is approximated by the range (maximum minus minimum) divided by the square root of twelve and the t-correction is put to unity.

$$s_3 = \frac{\max - \min}{\sqrt{12}}.$$

4. If the uncertainty is a possible model error in the life, strength, or load calculation, then the possible error is judged from engineering experience, suitably a judgement by means of

percentage error, +/- *e*%, the standard deviation is then approximated by the percentage error divided by 100 and the square root of three,

$$s_4 = \frac{e}{100 \cdot \sqrt{3}}.$$

5. If a possible model error can be described as a set of possible alternative models, then the standard deviation of the model results can be used as the uncertainty measure, adjusted as above by a *t*-correction.
6. If the uncertainty is of any other origin, such as possible bias in sampling, possible equivalence error between test environment and service, then the judgement methods as described above can often be used for finding a proper standard deviation.

Table: Values for the t-correction factor.

n	2	3	4	5	6	7-10	11-26	27-
t_n	**6.5**	**2.2**	**1.6**	**1.4**	**1.3**	**1.2**	**1.1**	**1.0**

5. Total Uncertainty Evaluation

For each source of uncertainty, the standard deviation, the t-correction and the sensitivity coefficient are multiplied. These numbers are squared and added to the overall uncertainty variance of the target. The square root of this variance is the overall statistical uncertainty measure.

6. Reliability and Robustness Evaluation

This statistical uncertainty measure is multiplied by the number 1.64 for the *statistical safety distance.* If the nominal target function (the difference in logs) exceeds this number, then the design reliability should be at least 95%.

The amount of exceedance is a measure of the extra safety distance, which should fulfil the designers demand about extra safety for approvement.

7. Improvement Actions

In case the design is not approved, there are different possibilities:

- Change the design to increase the strength or to reduce the loads.
- Refine investigations to diminish the dominating uncertainties estimated as possible errors.
- Limit the allowed usage to diminish the load variation.

Using the Spreadsheet Tool

Each identified uncertainty source has a row entry in the sheet below. The uncertainty name, standard deviation, *t*-correction and sensitivity coefficient are filled in and it is defined as a scatter source or an uncertainty source by a cross in the chosen column.

The anti-log of the target function values are filled in in C23 and C24 and the required safety factor in cell C29.

The values in the blue cells are evaluated by the tool and the design is approved if the calculated extra safety factor in cell F29 is not lower than the required in cell C29.

	A	B	C	D	E	F	G	H	I
1	**Evaluation of Uncertainties**								
2									
3	**Input**						**Result**		
4				**Sensitivity coefficient**	**t-correction factor**	**standard deviation**			
5	**Uncertainty components**	**scatter**	**uncert.**	**c**	**t**	**s**	**Scatter**	**Uncertainty**	**Total**
6	**Strength**								
7									
8									
9									
10	**Total Strength uncertainty**								
11									
12	**Load**								
13									
14									
15									
16	**Total Load uncertainty**								
17	**Total uncertainty**								
18									
19									
20	**Reliability Evaluation**								
21									
22	**Input**			**Result**				**Result (log-scale)**	
23	Median strength			Safety factor				Strength, mS	
24	Median Load							Load, mL	
25								Distance	
26									
27									
28	**Evaluation - Extra safely factor**			Variation safety factor				Variation dist.	
29	Required extra safety factor			Extra safety factor				Extra dist.	